AD-A179 579 EXPERIMENTAL RESEARCH ON COMPRESSIBLE TURBULENT SHEAR LAYERS VISCOUS-INVI.. (U) PENNSYLVANIA STATE UNIV UNIVERSITY PARK DEPT OF MECHANICAL EN.. G S SETTLES

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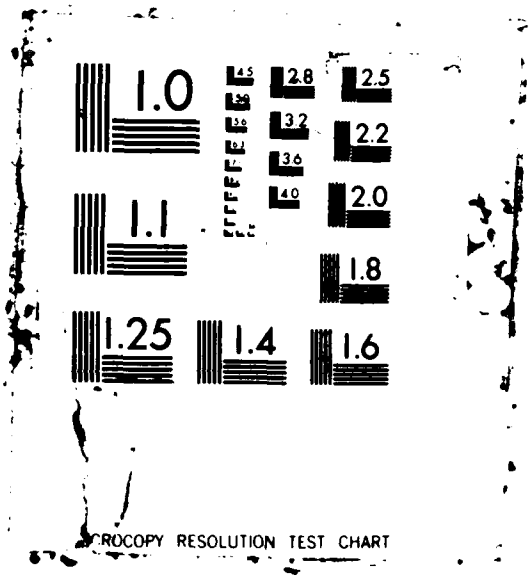
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1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT FURTHER DISTRIBUTION ONLY AS DIRECTED BY AFOSR/NA 4/7/87, OR HIGHER DOD AUTHORITY
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR- 87-0452
6a. NAME OF PERFORMING ORGANIZATION PENNSYVANIA STATE UNIV DEPT OF MECH ENGR	6b. OFFICE SYMBOL (If applicable)
7a. NAME OF MONITORING ORGANIZATION AFOSR/NA	
6c. ADDRESS (City, State and ZIP Code) 303 MECHANICAL ENGINEERING BLDG UNIVERSITY PARK, PA 16802	7b. ADDRESS (City, State and ZIP Code) BUILDING 410 BOLLING AFB, DC 20332-6448
8a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (If applicable)
9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR-84-0184	
8c. ADDRESS (City, State and ZIP Code) BUILDING 410 BOLLING AFB, DC 20332-6448	10. SOURCE OF FUNDING NOS PROGRAM ELEMENT NO. 61102F; PROJECT NO. 2917; TASK NO. A1; WORK UNIT NO.
11. TITLE (Include Security Classification) (U) EXPERIMENTAL RESEARCH ON COMPRESSIBLE TURBULENT SHEAR LAYERS VISCOUS-INVISCID INTERACTIONS, AND FLOW SEPARATION	
12. PERSONAL AUTHOR(S)	
13a. TYPE OF REPORT FINAL	13b. TIME COVERED FROM _____ TO _____
14. DATE OF REPORT (Yr., Mo., Day) 4/9/84	15. PAGE COUNT 13
16. SUPPLEMENTARY NOTATION	
17. COSATI CODES FIELD / GROUP / SUB GR	18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) INSTRUMENTATION, UNIVERSITY INSTRUMENTATION, DOD-URIP

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

THIS REPORT DESCRIBES THE DOD-UNIVERSITY RESEARCH INSTRUMENTATION INSTRUMENTATION PROGRAM EQUIPMENT ACQUISITION FOR PENSYLVANIA UNIV.

DTIC ELECTE S APR 24 1987 D E

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☒ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL HENRY E HELIN, CAPTAIN, USAF	22b. TELEPHONE NUMBER (Include Area Code) 202-767-4935
22c. OFFICE SYMBOL AFOSR/NA	

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE

UNCLASSIFIED

PSU-ME-86-R-0113

AFOSR-TR- 87-0452

FINAL SCIENTIFIC REPORT
on
AFOSR Grant 84-184

DoD-University Research Instrumentation Program
for the period 1 July 1984 - 30 June 1985

"Experimental Research on Compressible Turbulent Shear Layers, Viscous-Inviscid Interactions, and Flow Separation"

prepared by

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April 9, 1986

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH (AFSC)
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Chief, Technical Information Division

FINAL SCIENTIFIC REPORT ON AFOSR GRANT 84-184

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QUALITY INSPECTED 2

Optical and Photographic Equipment

Quantity	Mfg/Vendor	Item	Price
1	Omega	View camera kit/case	$ 568.50
1	Omega	Roll film adaptor	269.00
1	Polaroid	35mm auto processor	55.00
1	Polaroid	35mm slide mounter	14.00
5 rolls	Polaroid	Polagraph HC trans. film	44.75
5 rolls	Polaroid	Polachrome CS color film	39.75
2 boxes	Polaroid	35mm slide mounts (100 ea)	9.90
1	Bogen	Tripod	678.00
1	Redlake	Hycam II 400 ft. camera	8,375.00
1	Redlake	Shutter for Hycam II 72	36.00
1	Redlake	Shutter for Hycam II 36	36.00
1	Redlake	Shutter for Hycam II 18	36.00
1	Redlake	Shutter for Hycam II 7.2	36.00
1	Redlake	Carrying case for Hycam II	225.00
1	Canon	Zoom lens 16-100 mm	310.00
16	Univ. Video	Various sizes adaptors	37.80
27	Univ. Video	Various sizes cables	48.30
1	Univ. Video	Cable/connector kit	24.95
24	Univ. Video	Various sizes plugs	21.20
20	Univ. Video	Videocassettes (VHS)	179.00
20	Univ. Video	Storage boxes(videocassettes)	51.00
20	Univ. Video	Cartons	14.00
1	Univ. Video	Microphone	42.95
2	Univ. Video	Magnetic tape	19.90
3	Ealing Corp.	Rectangular Aperture	885.00
5	Ealing Corp.	40mm base & SCD pillar	285.00
5	Ealing Corp.	40mm base & short pillar	275.00
5	Ealing Corp.	90mm base w/vertical & Transverse slides	1,150.00
2	Ealing Corp.	Carrier w/ offset stem	150.00
2	Ealing Corp.	Spring grip lens holder	230.00
4	Ealing Corp.	50mm sliding lens holder	220.00
2	Ealing Corp.	40mm adjustable plane mirror	255.00
4	Ealing Corp.	Utility holder	140.00
10	Ealing Corp.	Standard mounting pin	130.00
15	Ealing Corp.	Long mounting pin	255.00
10	Ealing Corp.	Pin clamp	470.00
2	Ealing Corp.	Adjustable lens holder	330.00
3	Ealing Corp.	Adjustable plane mirror	255.00
1	Ealing Corp.	Polarizer/analyzer	596.97
2	Ealing Corp.	ND filter set	299.00
2	Ealing Corp.	Lamphouse	990.00
2	Ealing Corp.	Side-mount adapter	70.00
2	Ealing Corp.	Beam steering unit	298.00
1	Ealing Corp.	Variable density filter	575.00
3	Ealing Corp.	AR Laser safety goggles	345.00
1	Ealing Corp.	Multiple filter holder	119.00
2	Ealing Corp.	Lens chuck	330.00

Optical and Photographic Equipment, cont'd.

Quantity	Mfg/Vendor	Item	Price
1	Impulsphysics	Chronolite 8 Cranz-Schardin Camera System	$24,324.24
1	University Elec.	Panasonic VCR, 4 hd. VHS	1,056.12
1	University Elec.	Panasonic video camera	1,125.00
1	University Elec.	Panasonic video monitor	379.00
1	University Elec.	Case for VCR,hard shell	90.00
1	University Elec.	Service Manual for Panasonic VCR	42.50
1	Laser Ionics	Argon-Ion Laser	13,000.00
1	Aerotech	5mW He-Ne Laser	695.00
1	Aerotech	Mounting ring	35.00
1	Aerotech	Line generator	105.00

Transducers and Associated Equipment

Quantity	Vendor	Item	Price
1	Varian	Thermocouple guage	$ 159.00
1	Moore Prod.	Single loop digital controller	1,200.00
1	Moore Prod.	Transducer	250.00
4	Omega Eng.	Insulated thermocouples	176.00
3	Omega Eng.	Cement-on thermocouples	87.00
4	Omega Eng.	Unsheathed thermocouples	17.00
12	Omega Eng.	Thermocouple connectors	38.40
40	Omega Eng.	Thermocouple connectors	56.00
12	Omega Eng.	Jack panels	483.36
500 ft.	Omega Eng.	Extension grade chromel/ constantan leads	165.00
1	Omega Eng.	Portable calibrator, thermometer	765.00
1	Endevco	20 psig ultra-miniature pressure transducer	715.00
1	Endevco	100 psig ultra-miniature pressure transducer	715.00
1	Endevco	Signal conditioner	490.00
1	TSI, Inc.	Hot-wire Anemometer	3,330.00
1	TSI, Inc.	Monitor & power supply, 2 channel	1,350.00
1	TSI, Inc.	Modular cabinet with fan	290.00
2	TSI, Inc.	Standard straight hot-wire probe	220.00
1	TSI, Inc.	Upstream hot-wire probe	130.00
2	TSI, Inc.	Supersonic hot-wire probe	540.00
2	TSI, Inc.	Probe support	230.00
2	TSI, Inc.	90 deg. angle adapter	320.00
1	TSI, Inc.	Probe Support	120.00
1	TSI, Inc.	Mounting block	85.00
1	TSI, Inc.	Repair kit	130.00

Transducers and Associated Equipment, cont'd.

1	TSI, Inc.	Temperature comp. probe	490.00
1	TSI, Inc.	Shield	135.00
2	Scanivalve	Scanner w/ connector	2,680.00
2000 ft.	Scanivalve	Tubing	60.00
200	Scanivalve	Clamps	30.00
2	Scanivalve	Transmitter	412.00
2	Scanivalve	Solenoid drive	704.00
2	Scanivalve	Decoders	816.00
2	Scanivalve	Controller	1,030.00
2	Scanivalve	25 psi transducer	990.00
2	Scanivalve	Connector	161.00
100	Scanivalve	Tubulations	140.00
20	Scanivalve	Tube connector	27.00
20	Scanivalve	Tube connector	36.00
20	Scanivalve	Tube connector	40.00
1	Omega Eng.	Digital thermocouple indicator	615.00
5	Omega Eng.	Thermocouples	250.00
2	Omega Eng.	Cement-On thermocouples	58.00
1	Omega Eng.	Thermocouple	39.00
100 ft.	Omega Eng.	Duplex TC wire	138.00
1	Omega Eng.	Magnetic Relay	55.00
1	Validyne	12.5 Pressure transducer	385.00
1	Validyne	20.0 Pressure transducer	385.00
1	Validyne	50.0 Pressure transducer	385.00
1	Validyne	80.0 Pressure transducer	385.00
1	Validyne	200.0 Pressure transducer	385.00
1	Validyne	Pressure transducer kit	650.00
10	Validyne	O-rings	19.00
10	Validyne	Body bolts	19.00
10	Validyne	Bleed screws	9.50
10	Validyne	Bleed screw gaskets	9.50
1	Validyne	Bleed screw hex wrench	1.00
1	Validyne	Body bolt spline wrench	1.00
1	Validyne	Transducer simulator	520.00
6	Validyne	Connector and cable	234.00
2	Validyne	Connector and cable	74.00
1	Validyne	Connector and cable	40.00
1	Validyne	Connector and cable	63.00
1	Validyne	Absolute pressure transducer	450.00
1	Validyne	Cable for transducer	39.00
1	Validyne	Potentiometer modules	780.00
1	Validyne	Modular conditioning system with terminals	1,470.00
2	Validyne	Dual channel AC/DC buffer amplifier	350.00
2	Validyne	High-gain carrier demodulator	520.00
5	Validyne	Dual channel carrier demodulator	975.00
10	Validyne	Thermocouple signal cond.	1,950.00
2	Validyne	Frequency-voltage converter	260.00
1	Validyne	Plug-in module connector ext.	85.00
1	Validyne	Card Extractor	35.00

Minor Components

Quantity	Vendor	Item	Price
1	Hankinson	Centriflex filter/housing	$ 426.00
5	Hankinson	Replacement filter sleeves	200.00
4	Sargent-Welch	Lab Jack	377.60
1	Sargent-Welch	Vacuum Pump	660.00
2	Penny & Giles	Single track potentiometer with side mounting kit	236.80
2	Pitt. Valve	Union Cross	15.00
10	Pitt. Valve	Cap	9.70
10	Pitt. Valve	Plug	9.00
10	Pitt. Valve	Nut	2.80
10	Pitt. Valve	Tube adaptor	21.00
5	Pitt. Valve	Hose connector	5.00
10	Pitt. Valve	Tube hose connector	
20	Pitt. Valve	Inserts for PVC	9.20
5	Pitt. Valve	Male run tee	23.25
5	Pitt. Valve	Male branch tee	23.25
2	Pitt. Valve	5-way ball valve	87.40
1	Pitt. Valve	3-way ball valve	32.00
1	Pitt. Valve	3-way ball valve	32.00
1	Pitt. Valve	3-way ball valve	32.00
2	Pitt. Valve	2-way ball valve w/vent	43.60
3	Pitt. Valve	2-way ball valve w/vent	65.40
2	Pitt. Valve	Relief valve	31.40
1	Pitt. Valve	Relief valve	15.70
1	Pitt. Valve	Fine metering valve	25.00
9	Pitt. Valve	Filter	358.20
1	Pitt. Valve	Inline filter	14.70
1	Pitt. Valve	Plug valve	19.70
1	Pitt. Valve	Check valve	10.60
1	Pitt. Valve	Check valve	10.60
1	Pitt. Valve	Valve	13.80
1	Pitt. Valve	Quick connect body	8.00
1	Pitt. Valve	Quick connect stem	9.20
5	Pitt. Valve	Female fitting	10.00
100	Pitt. Valve	Insert	42.78
10	Pitt. Valve	Male connectors	14.50
100	Pitt. Valve	Nut	26.04
1 pack	Pitt. Valve	Ferrule pack	42.78
10	Pitt. Valve	Pipe plug	20.00
10	Pitt. Valve	Union elbow	33.00
1	Pitt. Valve	1/4" to 1/2" FPT connector	3.65
2	Pitt. Valve	1/4" to 1/2" MPT connector	5.80
3	Vita Needle	Gauge 7 steel tube	27.00
3	Vita Needle	Gauge 9 steel tube	27.00
3	Vita Needle	Gauge 12 steel tube	16.20
3	Vita Needle	Gauge 15 steel tube	16.20
3	Vita Needle	Gauge 18 steel tube	13.50

Minor Components, cont'd.

Quantity	Vendor	Item	Price
1	Arrow Star	Glass door bulletin board	$ 101.25
3	Vita Needle	Gauge 21 steel tube	10.80
3	Vita Needle	Gauge 26 steel tube	10.80
3	Vita Needle	Gauge 32 steel tube	13.50
4	Pitt. Valve	2-way ball valve w/vent	87.20
5	Pitt. Valve	1/4" union cross	38.50
4	Pitt. Valve	3-way ball valve	128.00
20	Pitt. Valve	1/4" plug	18.00
10	Pitt. Valve	1/4" tees	54.00
10	Pitt. Valve	1/4" unions	18.00
10	Pitt. Valve	1/4" swagelok to 1/4" MPT union	14.50
10	Pitt. Valve	1/4" swagelok to 1/6 MPT EL	32.00
3	Pitt. Valve	Snubber	69.00
5	PSU Gen. Store	Fitting 1/4" x 1/8" MPT	8.35
15	PSU Gen. Store	Fitting 1/4" x 1/8" MPT EL	51.75
10	PSU Gen. Store	Fitting 1/4" T union EL	37.95
10	PSU Gen. Store	Fitting 1/4" front ferrule	2.60
10	PSU Gen. Store	Fitting 1/4" rear ferrule	2.40
10	PSU Gen. Store	Fitting 1/4" T tee	62.00
5	PSU Gen. Store	Fitting 1/4" T union	9.65
1	E. M. & S.	Hankinson Centriflex filter and housing	426.00
1	E. M. & S.	Replacement filter and sleeve	200.00

Parts and Materials for Data Collection and Calibration System

Quantity	Mfg/Vendor	Item	Price
1	Abbeon Cal	Timer, heavy duty	$ 26.95
1	Controlamatic	Regulator	235.00
2	Controlamatic	Nuts	5.00
1	Tecmar	Expansion Chassis for IBM PC XT	756.00
1	Metrabyte	24 bit I/O interface	109.00
1	Metrabyte	Terminal board	109.00
1	Metrabyte	37-pin cable	34.00
2	Metrabtye	Modem boards	690.00
1	Metrabyte	16 channel A/D	895.00
1	Metrabyte	Terminal board	89.00
1	Metrabyte	Cable	46.00
2	PSU Gen. Stores	Swivel chairs	454.54
3	Designware	Ribbon cartridges for NEC P2 Pinwriter	31.50
1	Designware	RS-232 cable for HP plotter/IBM PC	25.00
4	Designware	HP 0.7mm black pen	21.00
2	Designware	HP 0.3mm black pen	11.66
1	Designware	HP plotter paper	15.00
1	Designware	Energraphics plotter option for IBM PC (Enertronics Res.)	80.00
1	Designware	dBASEII to dBASEIII exchange kit (Ashton-Tate)	160.00
1	Designware	IBM PC printer cable parallel port, 25/36 pin	37.50
1	PSU Gen. Stores	IBM PC XT computer, including monochrome display, display and printer adapter, color graphics adapter, color monitor	4,190.00
1	Designware	Data Digitizer for IBM PC XT	710.00
1	Designware	8087 arithmetic coprocessor	310.00
1	Designware	AST expansion board	650.00
2	Marlow Assoc.	Upright electronic cabinet	1,200.00
2	Marlow Assoc.	Desk top for above	222.00
8	Marlow Assoc.	Panels for above	178.00
2	Marlow Assoc.	Outlet strips for above	30.00

Miscellaneous

Charges for Electronic Design Services	$ 1,000.00

Basic Instruments, Equipment, and Tools

Quantity	Mfg/Vendor	Item	Price
1	Williams Bros.	Universal bevel protractor	$ 173.35
1	Force Electric	Milling machine and associated tools	1,985.00
1 ea.	PSU Gen. Stores	Paper punch, binder, index, lettering	19.88
1	PSU Gen. Stores	Broom	6.19
1	PSU Gen. Stores	Wisk broom	1.87
1	PSU Gen. Stores	Dust pan	1.50
1	PSU Gen. Stores	Felt-tip black pen	.12
1	TEAC	4-channel open reel tape recorder	400.00
1	Arrow Star	Jib crane	376.00
1	Arrow Star	I-beam trolley	46.95
1	Arrow Star	Work bench	47.25
1	Arrow Star	Closed shelving	124.35
1	Arrow Star	Rolling steps	80.10
1	Abbeon Cal	Impact wrench	240.00
1	Abbeon Cal	Universal joint	24.50
1	Abbeon Cal	Extension bar	9.80
1	Abbeon Cal	Emergency light	86.00
1	Abbeon Cal	36 x 48 board kit	159.00
1	Abbeon Cal	rotangle protractor	16.00
1	Transcat	Dew Point Indicator	997.00
2	Ithaco	Model 4302 Filter	2,890.00
1	Hewlett Packard	DC Power Supply 0-40 VDC	1,400.00
1	Hewlett Packard	DC Power Supply 0-50 VDC	370.00
1	Hewlett Packard	External Time Base	490.00

Wind Tunnel Test Section Assembly

1	C. B. Ives Inc.	8" Fisher-type steel control valve	$ 4,433.90
1	C. B. Ives Inc.	line bolting for 300# flange	70.20
1	C. B. Ives Inc.	Valve positimer	280.00
1	PSU Engr. Shop	Flow channel assembly	15,375.68
1	Microtol Engrg.	Pneumatic model injection system	3,181.02
1	Velmex	Unislide assembly and hardware for probe drive	1,283.00
			$153,864.00

II. Discussion of Equipment List

As detailed in the Proposal which led to the subject Grant, the thrust of this effort has been to outfit and upgrade Penn State's Supersonic Wind Tunnel Laboratory with modern instrumentation so that research in support of national defense can be conducted. The subject area of this research is viscous-inviscid interactions in supersonic flight, an area of great concern in DoD's current and future plans (e.g. advanced tactical aircraft, transatmospheric vehicles, missiles and space shuttle-type vehicles). It happens that there are extremely few academic institutions in the United States with both the facilities and staff to conduct such research and to train students in this area.

The subject Grant has been very effective in helping to establish this capability at Penn State. In particular, the several categories of instruments and equipment listed in the previous section of this report reflect improvements in both the function of the wind tunnel facility and in our ability to acquire and reduce data in a modern, relatively painless way.

The process of upgrading the PSU Supersonic Wind Tunnel for research use has been an evolutionary one. Many man-hours have been spent in determining the necessary facility improvements and in spending the available funds in the most productive way. Indeed, this evolutionary process is still continuing, though the facility is now functional for research.

As a result, we found it necessary to make some adjustments to the originally-proposed equipment list during the course of the Grant, in order to insure that the Grant funds would be used most effectively for the stated purpose. Those adjustments are described below.

Approximately 2/3 of the 37 items listed in the original grant document were acquired as planned (though prices varied somewhat due to manufacturer price adjustments in the interim). Those items not acquired as originally planned are listed below:

1) Heat-Flux Gauges
2) Electronic Shutter
3) Chopper
4) Cathetometer
5) Photometer
6) High-Voltage Power Supply
7) Counter
8) Instrument Amplifier
9) Stroboscope
10) RMS Voltmeter
11) Datacopy camera and software
12) Darkroom equipment
13) Technician salary

The reasons why these items were not acquired are as follows: Item 1 was found not be commercially available in suitable form.

Items 9 and 13 were covered by alternate funding available at the time. Items 11 and 12 were judged of secondary importance due to related equipment available in nearby laboratories. The remainder of the items listed were superceded in importance by emerging requirements during the Grant period which rose to first priority in order to accomplish the goals of the Grant. The disposition of the approximately $32,000 represented by these items (21% of the total grant amount) is described below. (Only items over $1,000 are discussed for purposes of brevity.)

During the Grant period it became clear that a dedicated microcomputer with A/D capability was a necessary element of the data collection and calibration console which was not originally budgeted. This item (IBM PC XT and accessories) accounts for $7,962. Further, replacement of the main wind tunnel control valve ($14,785.) was found to be required so that the facility could be functional for research use. Electronic cabinets ($1,630) for the data acquisition console, a small milling machine ($1,985) for test model modifications, parts for a flow channel probe drive mechanism ($1,283) and a digital controller for the wind tunnel stagnation pressure control ($1,200) constitute less expensive but still important items not originally budgeted. The remaining $3,000 freed by budgeted items not purchased was consumed by price increases on some items, shipping costs, and miscellaneous small parts and fittings.

In summary, we hope the above discussion provides adequate justification for those variations from the original budget which did occur. Again, we feel these variations were absolutely necessary in order to accomplish the goals of the Grant. Finally, we believe the DoD-URIP Program has had a major positive impact in the present case in helping to establish a unique university facility which is now functional in DoD-funded and related research studies. (See the following section.)

III. Summary of Current Research Projects Aided by the Equipment Acquisitions

1) Title: Experimental Research on Swept Shock Wave Boundary Layer Interactions
Sponsor: U. S. Air Force Office of Scientific Research
Grant Number: AFOSR-86/0082
Duration/$ Amount: 4/1/86 - 3/31/87 $72,000.00
Principal Investigator: Gary S. Settles

This DoD-sponsored research study is aimed at a better understanding of Mach number and facility effects in an important class of three-dimensional shock wave/boundary layer interactions. It constitutes the first phase of the research described in the original DoD-URIP proposal. There is, as well, a strong element of the development of new instruments and techniques in this study. The optical equipment acquired under the DoD-URIP program is already being put to use.

2) Title: Mach Number Effects on 3D Shock Wave Turbulent Boundary Layer Interaction Regimes and Scaling - An Experimental Study in Support of CFD Code Validation
Sponsor: NASA-Ames Research Center
Grant Number: NCA2-1R589-502
Duration/$ Amount: 4/1/84 - 3/31/87 $80,000.00
Principal Investigator: Gary S. Settles

This research, though not DoD-sponsored, shares some common goals with that described above. The key issue under study is the effect of Mach number on a fin-generated shock/boundary layer interactions such as those generated by the control surfaces of high-speed aircraft and missiles. The Principal Investigator is working closely with NASA-Ames personnel to use the research results in concert with NASA's advanced CFD capabilities.

3) Title: Shock Wave/Turbulent Boundary Layer Interaction Experiments in Support of CFD Code Verification
Sponsor: NASA Lewis Research Center
Grant Number: NAG3-527
Duration/$ Amount: 2/1/84 - 12/31/86 $50,000.00
Principal Investigator: Gary S. Settles

This effort is aimed at obtaining accurate, detailed skin friction and heat transfer data in shock wave/turbulent boundary layer interactions. The support of NASA-Lewis stems from their need for benchmark experiments for CFD code validation. Our perspective is somewhat wider, in that we intend to get more from these experiments than simply data sets. The current experiments concern 2D compression corner interactions with and without separation at Mach 2.5. Later experiments are planned in swept interactions as well. In particular, we have developed a version of the laser skin friction interferometer instrument in order to obtain proper skin friction readings, since no other known instrument appears capable of this in strong adverse pressure gradients.

4) Title: Exploratory Experiments on the Shock Wave-Vortex Interaction Phenomenon
Sponsor: NASA-Ames University Consortium
Grant Number: NCA2-49
Duration/$ Amount: 6/1/85 - 5/31/87 $60,000.00
Principal Investigator: Gary S. Settles

This research effort is a highly exploratory look at an important phenomenon of high-speed flight: the interaction of a shock wave with a vortex. Since previous work in this area is almost non-existent, we hope to make a significant contribution to new knowledge early in this program.

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